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The Use of Automotive Glycol Antifreeze Test Strips for Determining the Freeze Point of Glycol-Based Aircraft Deicing Fluid

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16. Abstract

This Technical Note documents a series of tests performed to determine the accuracy of automotive glycol antifreeze test strips when used to measure the freeze point of glycol-based deicing and anti-icing fluids. Also employed in the tests was a refractometer, the currently accepted method used to determine de/anti-icing fluid freeze points. Varying concentrations of water and de/anti-icing fluid were used to provide a variety of test freeze points. The results of the two freeze point measurement methods are compared and discussed, and a recommendation is made.

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EXECUTIVE SUMMARY

Aircraft deicing and anti-icing fluid mixtures must be tested prior to initial use to determine their freeze point. Federal Aviation Administration (FAA) Advisory Circulars AC 120-58 ''Pilot Guide - Large Aircraft Ground Deicing'' and AC 20-117 ''Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing'' indicate that the residual fluid on aircraft surfaces following deicing operations employing Type I deicing/anti-icing fluids must have a freeze point of at least 18°F (10°C) below the outside air or aircraft skin temperature, whichever is lower. A refractometer is recommended by deicing fluid manufacturers for determining the freeze point of these mixtures. As part of its ''Aircraft Ground Deicing and Anti-icing Program'', an air carrier had requested to use automotive antifreeze test strips in lieu of a refractometer to check the freeze point of glycol-based aircraft deicing fluids. The Flight Safety Research Section (AAR-421) at the FAA Technical Center was requested by the Flight Standards Service to investigate the use of color comparison glycol automotive antifreeze test strips to measure the freeze point of aircraft deicing fluid.

The Technical Center conducted a series of tests in which the test strips were employed to measure the freeze point of varying concentrations of glycol-based deicing and anti-icing fluids under controlled conditions. For comparison, a refractometer was used in determining the freeze point of the test mixtures.

The test data showed very poor accuracy for the test strips, with mean errors as high 37.7°F, while the refractometer was usually accurate to within 2°F.

A recommendation is made that the use of automotive antifreeze test strips for measuring the freeze point of aircraft deicing and anti-icing fluids not be approved. It is further recommended that those tasked with field testing the freeze point of aircraft deicing and anti-icing fluids should continue using the methods prescribed by the fluid's manufacturer, which is usually a portable refractometer.

BACKGROUND

Aircraft deicing and anti-icing fluid mixtures must be tested prior to initial use to determine their freeze point. Federal Aviation Administration (FAA) Advisory Circulars AC 120-58 ''Pilot Guide - Large Aircraft Ground Deicing'' and AC 20-117 ''Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing'' indicate that the residual fluid on aircraft surfaces following deicing operations employing Type I deicing/anti-icing fluids must have a freeze point at least 18°F (10°C) below the outside air or aircraft skin temperature, whichever is lower. The deicing mixtures used by airlines consist of premixed fluids (typically 50/50: 50% glycol and 50% water), or varying concentrations of glycol-based deicing fluid concentrate and water mixed during application. Excluding premixes, mixtures are typically varied according to existing temperature conditions in order to use the deicing fluid concentrate in the most economical manner possible. The method recommended by deicing fluid manufacturers for determining the freeze point of these mixtures is to use a refractometer. There are several refractometers being used by airlines for checking deicing fluid freeze points, and they are of rugged design for outdoors employment. They normally sell for less than $100.00.

The Flight Safety Research Section (AAR-421) at the FAA Technical Center was requested by the Flight Standards Service to investigate the use of color comparison glycol automotive antifreeze test strips to measure the freeze points of aircraft deicing fluids. As part of its approved Aircraft Ground Deicing and Anti-icing Program, an air carrier had requested to use these automotive antifreeze test strips in lieu of a refractometer to check the freeze points of glycol-based deicing fluids.

The Technical Center contacted a number of aircraft deicing fluid manufacturers, and all indicated that the only method they recommended for checking their products' freeze points was through the use of a refractometer. All felt that the automotive antifreeze test strips generally suffered from a lack of resolution and accuracy and therefor were inadequate for the task of testing aircraft deicing fluids. The following reasons were given:

- Resolution. The test strips are dipped in the liquid to be measured, and a chemically treated pad on the strip changes color to indicate the freeze point of the glycol mixture. The pad is then compared to a color scale provided by the test strip manufacturer. There are 5 color scales corresponding to freeze points of +10, 0, -10, -30, and -60°F. The deicing fluid manufacturer felt that this small number of comparison ''colors'' was inadequate for determining requisite freeze points of the deicing fluid mixtures. This trepidation was reinforced by the fact that the ''colors'' are actually varying shades of green. Another point of concern expressed by the deicing fluid manufacturers was the variability of color rendition on the comparison scale due to normal color printing variances and the fact that the strips would be used under varying light conditions (daylight and artificial light of varying color temperatures and intensities). Conceivably, these variables could cause difficulty in properly matching the test strip pad color to the reference (see figure 1).

- Accuracy. The accuracy of the test strips was stated by the manufacturer to be ''± one half color change.'' This tolerance varies between ±5 to ±15°F depending on the temperature range. The deicing fluid manufacturers felt this accuracy to be inadequate. The manufacturer of the most widely used refractometer states an accuracy of ±2°F, which is considered adequate.

TEST METHODOLOGY

The Technical Center conducted a series of tests in which the test strips were employed to measure the freeze point of varying concentrations of glycol-based deicing and anti-icing fluids under controlled conditions.

For comparison, in addition to using the test strips, it was decided to use a refractometer in determining the freeze point of the test mixtures.

The test strips were manufactured by Environmental Test Systems of Elkhart, Indiana. They are marketed under the name of CoolTrack Coolant Test Strips and are packaged in a small plastic jar containing 50 strips. Instructions for use are attached as a label on the jar, along with the color references (see figure 1) used for comparison with the test strip after it is dipped in the test sample. The jar is marked with an expiration date. The strips used for this test were marked with an expiration date of November 1996. The strips are packaged with a silica gel desiccant packet to protect against excess humidity. The strips are approximately 3.25'' long and 0.375'' wide. There are two pads on one end of each strip. The pad on the tip of the strip is the one used to determine freeze point. The other pad, approximately 0.5'' from the freeze point determination pad, is used to measure the reserve alkalinity level of automotive coolant as a measure of acid corrosion protection. As it had no use in testing deicing fluid, its capability was not evaluated.

The refractometer used for these tests was typical of those being used in the field. See appendix B for a description and operating methodology.

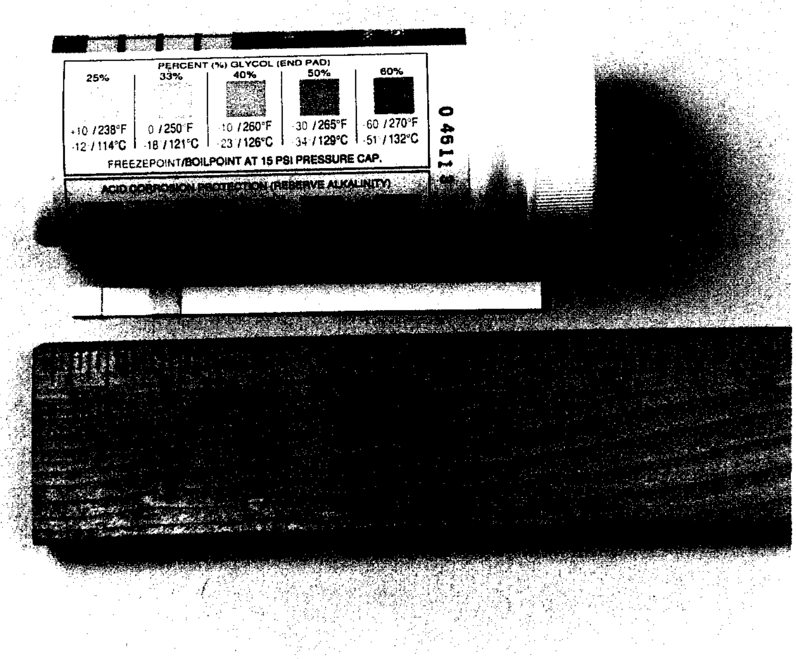

FIGURE 1. GLYCOL TEST STRIPS AND COLOR COMPARISON CHART

While the thrust of the concern was associated with the determination of the freeze point of Type I deicing fluids, it was decided to also include test samples of Type II glycol anti-icing fluid for evaluation. This was done to assess the effects, if any, the different chemical compositions of Type I and Type II deicing and anti-icing fluids have on the accuracy of the two freeze point measurement methods.

For the tests, 11 samples each of the deicing and anti-icing fluids were prepared. The deicing/anti-icing fluid concentrate to water ratios ranged from 0% (pure water) to 100% (pure concentrate) in 10% increments. Both the Type I and Type II deicing and anti-icing fluid concentrates were ethylene glycol-based. Six test subjects were employed for each round of testing. Of the 6, only two had previous experience using a refractometer, and none had used the test strips. During the first series, the deicing fluid samples were measured using both methods. During the second series, the tests were repeated for the anti-icing fluid samples. Of the 6 subjects used for each series of measurements, 4 participated in both.

The test subjects were given a brief overview of the test and were then told to measure the samples using the instructions supplied by the manufacturers of the test devices. A log sheet (appendix A) was provided for entry of the measured values. Space was provided on the log sheet to allow for comments, both for each sample and for the overall test.

TEST RESULTS

TYPE I DEICING FLUID TEST RESULTS.

While concentrations of deicing fluid to water ranged between 0% to 100%, concentrations above 60% were ignored due to the fact that the manufacturer publishes accurate freeze points only for concentrations of less than 60% and above 88%. For concentrations between 60% and 88%, the manufacturer states that the freeze point is less than $-50^{\circ}F$. Concentrations greater than 88% were also ignored as they were out of the accurate measurement range of both test methods. Table 1 shows the predicted and the actual readings for the applicable temperature ranges using both test methods. The predicted freeze points were taken from the deicing fluid manufacturer's data.

Using the test strips, for 0% concentration (freeze point of 32°F) all 6 test subjects read (interpreted) the freeze point to be +10°F. The same interpretation (freeze point of 10°F) was given by all 6 test subjects for concentrations of 10% (freeze point of 26°F), 20% (freeze point of 17°F) and 30% (freeze point of +5°F). This resulted in mean errors ranging from 5 to 22°F. This indicates that the test strips could not resolve differences between pure water and deicing fluid concentrations of 10%, 20% and 30%. Over the same range of concentrations, the refractometer produced readings that were within 3°F of the predicted values except for two readings (20% concentration for subject 4, and 30% for subject 5). Considering the consistency of other refractometer readings over the entire range, it is probable that these two readings were due to test subject error. Nevertheless, with the suspect readings included, the averages of the refractometer readings produced a maximum mean error of 3.5°F.

For the 40% concentration (freeze point -5°F), 5 out of 6 subjects continued to read a freeze point of +10°F using the test strips. One subject interpolated a reading of +5°F. This produced an average reading of +9.2°F and a mean error of 14.2°F. Concentrations on the order of 30% to 40% are typical for non-premix deicing fluid mixtures. Five of the 6 refractometer readings were -5°F and the other reading was -4°F, for a mean error of 0.2°F.

For the 50% concentration (freeze point -25°F), all 6 subjects read 0°F using the test strips, for a mean error of 25°F. The refractometer readings ranged from -23 to -25°F, producing a mean error of 0.7°F.

Using the test strips with the 60% concentration (freeze point -46°F), 5 out of 6 subjects got readings of -10°F, and one got a reading of 0°F, for an average reading of -8.3°F and a mean error of 37.7°F. The range of refractometer readings was from -47 to -50°F, with an average reading of -49°F and a mean error of 3°F.

TABLE 1. GLYCOL TEST STRIPS VERSUS REFRACTOMETER RESULTS

Type 1 Deicing Fluid Test Results

Test Solution Concentration (Fluid/Water)	Predicted Freezepoint Degrees F	Test Results In Degrees F												Test Strip Results Degrees F		Refractometer Results Degrees F	
		Subject 1		Subject 2		Subject 3		Subject 4		Subject 5		Subject 6					
		Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	AVG	Error	AVG	Error
0%	32	10	32	10	32	10	32	10	32	10	31	10	32	10	22	31.8	0.2
10%	26	10	25	10	24	10	25	10	25	10	24	10	25	10	16	24.7	1.3
20%	17	10	17.5	10	18	10	15	10	8	10	16	10	18	10	7	15.8	1.2
30%	5	10	7	10	8	10	7	10	7	10	15	10	7	10	3	8.5	3.5
40%	-5	10	-5	10	-5	10	-5	5	-4	10	-5	10	-5	9.2	14.2	-4.8	0.2
50%	-25	0	-25	0	-24	0	-25	0	-25	0	-23	0	-24	0	25	-24.3	0.7
60%	-46	-10	-48	0	-47	-10	-50	-10	-50	-10	-49	-10	-50	-8.3	37.7	-49	3

Type 2 Anti-icng Fluid Test Results

Test Solution Concentration (Fluid/Water)	Predicted Freezepoint Degrees F	Test results In Degrees F												Test Strip Results Degrees F		Refractometer Results Degrees F	
		Subject 1		Subject 2		Subject 3		Subject 4		Subject 5		Subject 6					
		Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	Strips	Refract	AVG	Error	AVG	Error
0%	32	10	32	10	32	10	32	10	32	10	32	10	32	10	22	32	0
50%	-2	0	-4	0	-3	0	-3	10	-2	5	-2.5	10	-2.5	4.2	16	-2.8	0.8
100%	<-38	-20	CS	-30	CS	-10	CS	-10	CS	-20	CS	-10	CS	-16.7	>21.3	CS	-

CS: Clear Screen

TYPE II ANTI-ICING FLUID TEST RESULTS.

Type II fluids for anti-icing purposes are normally used in concentrated form. However, the manufacturer also publishes freeze point data for a 50% concentration. The results of readings for these two concentrations, along with plain water, are presented.

The results for 0% concentration (water) mirrors the results from the Type I fluid trials. The test strips could only read +10°F (the highest reading available), once again producing a mean error of 22°F. All of the refractometer readings were +32°F for a mean error of 0.

For the 50% concentration (freeze point of -2°F), the test strips produced a range of readings from 0 to +10°F, resulting in an average reading of +4.2°F and a mean error of 6.2°F. The refractometer produced readings between -2°F and -4°F, for an average of -2.8°F and a mean error of 0.8°F.

For the neat concentration (freeze point of less than -38°F), the test strips gave readings between -10 and -30°F for an average reading of -16.7°F and a mean error of at least 21.3°F. The refractometer produced a clear screen reading across the board, which indicated a freeze point of less than -50°F, indicating a very high concentration of fluid.

ANALYSIS

The results using the test strips were disappointing. At low concentration levels the strips produced the same, or essentially the same reading for Type I fluid concentrations of 0 to 40%. While the test strips provided the same +10°F reading over this range, the actual freeze points of the test mixtures varied from +32 to -5°F. For much of the continental United States, this range of freeze points is likely to be the most prevalent, and consequently, the most tested for. In this range, the test strips provided no usable resolution of freeze point. At Type I fluid concentrations of 50% and 60%, the strips underestimated the freeze points an average of 25 and 37.7°F respectively. Using the test strip readings would cause the operator to assume the mixture's freeze point was much higher than it really was and could cause the operator to increase the mixture's concentration above 70%, into the region where, due to the characteristics of glycol-based fluids, the freeze point begins to rise!

When testing Type II anti-icing fluid, the test strips proved to be relatively accurate when measuring the 50% concentration. But once again, they greatly underreported the freeze point of the neat concentrations and could not read a freeze point higher than +10°F. Since many airlines normally use anti-icing fluids at full strength, freeze point testing is often used as a method of detecting deterioration, contamination, or unwanted dilution. The glycol test strips cannot perform this task with any acceptable level of accuracy.

The refractometer, on the other hand, lived up to its reputation as an accurate means of measuring the freeze point of glycol based deicing fluids. Whether measuring varying concentrations of Type I or Type II fluids or water, the results were no more than 3.5°F from the predicted value. In fact, the usual errors were more in the order of 1°F. The resultant 3.5°F mean error contained a suspected data point that produced a large skew to the average.

RECOMMENDATIONS

Based upon the test data, the glycol test strips as currently supplied have unacceptably poor resolution and accuracy when measuring the freeze point of glycol based aircraft deicing and anti-icing fluids. Conversely, the refractometer provided consistently accurate measurements of the deicing and anti-icing fluid freeze points.

It is therefore recommended that the use of automotive antifreeze test strips for measuring the freeze point of aircraft deicing and anti-icing fluids not be approved. Pending the development and evaluation of new instruments, those tasked with field testing the freeze point of aircraft deicing and anti-icing fluids should continue using the methods prescribed by the fluid's manufacturer, which is usually a portable refractometer.

Appendix A

Test Log Sheet

Glycol Test Strip Test Log

Deicing Fluid Type:_______ Test Conductor:______________________________ Date:_______

Test Sample:	Strip Freeze Point Reading:	Refractometer Reading:	Comments:
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			

Additional Comments:____

Appendix B

Refractometer Description and Operating Methodology

Theory of Operation

The refractive index of a material is an optical measurement of its ability to bend a beam of light passing through it. The refractive index of deicing/anti-icing fluid gives an indication of the concentration of glycol in a glycol/water mixture. A refractometer, of the type shown in figure B-1, is an instrument often employed to measure antifreeze protection of a given mixture on the basis of the mixture's refractive index. The refractometer gives an immediate reading of the mixture's freezing point within an accuracy of 2°F. The refractometer automatically corrects for fluid temperature variance and provides an accurate reading for hot or cold fluids.

Physical Description

The refractometer used in these tests is of roughly cylindrical shape at the viewing end and tapers to a roughly flat shape at the sample end (figure B-1). It is approximately 9.0'' long and 1.5'' in width. It is composed of a die-cast metal body which is encased in a red, hard rubber covering. The viewing end consists of a black plastic cylinder which protrudes from the rubber covering and contains a glass lens. The sample end consists of a piece of flat rectangular glass approximately 1'' in length and 0.3'' in width, flush mounted in a sloping portion of the flattened end of the tester. A hinged clear acrylic prism is held by spring tension against the glass sample area. The prism has an opening to admit the sample and holds it against the glass surface during the measurement. The prism is opened after the measurement has been competed to allow cleaning of the glass surface and the inside surface of the prism. The body of the tester has storage areas for two sample collectors: a syringe for sampling glycol and a dip stick for sampling battery acid. In addition to testing the freeze point of glycol-based mixtures, the refractometer can measure the specific gravity of battery acid to determine charge level. This feature was ignored during the test.

Method of Operation

The deicing fluid to be measured is sampled by the syringe. A few drops of the sample are placed in the opening of the prism,

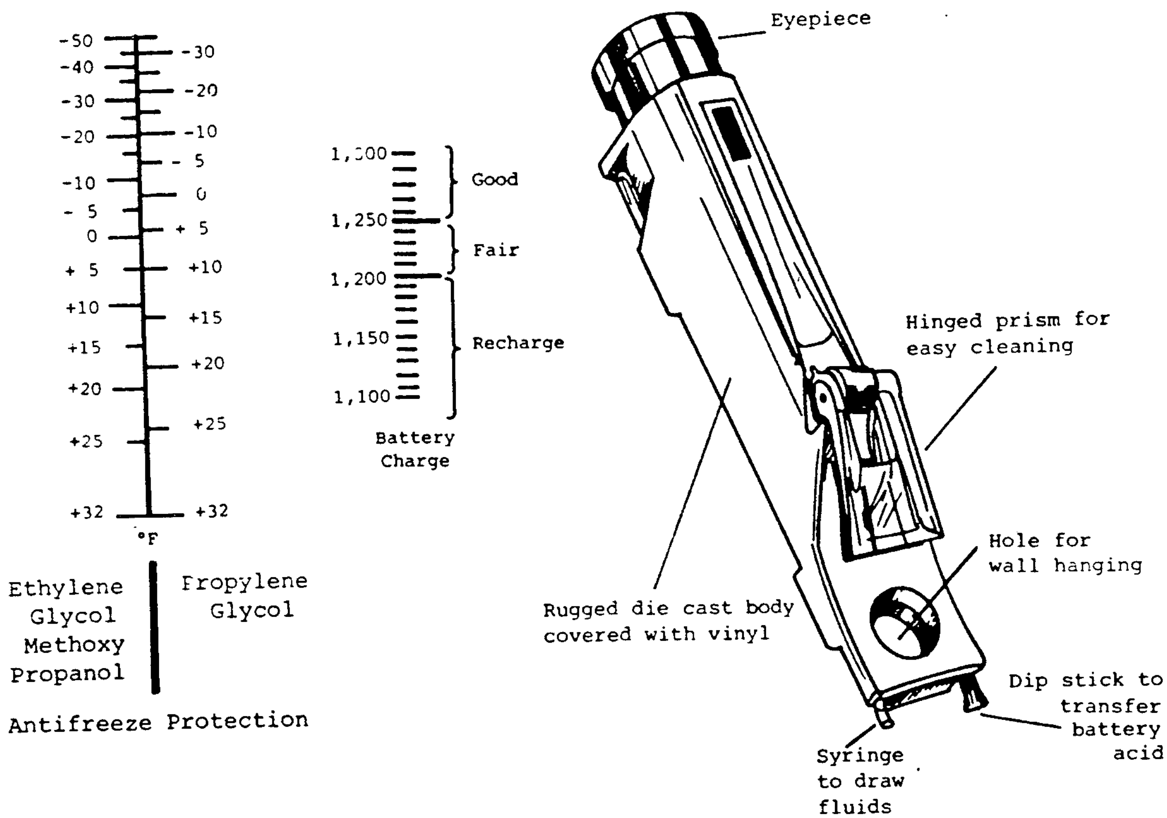

FIGURE B-1. REFRACTOMETER AND FREEZEPOINT MEASUREMENT SCALES and the sample distributes itself over the glass sample area. The measurement is taken by pointing the sample end of the refractometer toward a source of light and looking through the lens at the other end. The view inside the refractometer contains two scales (the relative position of which is reversed in figure B-1). The one on the left is for measuring battery acid and was not utilized. The scale on the right is for measuring the freeze point of the deicing fluid and is calibrated in $^{\circ}$F (the refractometer is available in a model calibrated in $^{\circ}$C). The glycol measurement scale consists of a vertical line with tick marks on either side of the line. The tick marks on the left side of the line are used for measuring ethylene glycol-based deicing fluids. The tick marks on the right side of the line are for measuring propylene glycol-based deicing fluids. The range of measurement is +32 to -84°F for ethylene glycol-based deicing fluids, and +32 to -60°F for propylene glycol-based deicing fluids (the refractometer used for these tests was an improved model with a greater range of measurement than what is shown in figure B-1). The scale will not be visible until liquid is placed on the measurement glass. When a sample is placed on the glass, the dark area rises to form a distinct line of light and dark that crosses the scale perpendicularly, indicating the value for the measurement. If the screen clears completely, the sample concentration has exceeded the range of the scale.